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GENERAL INFORMATION

COMPACT
disc
DIGITAL AUDIO

MAIN PARAMETERS OF

- DISC
- OPTICAL STYLUS
- MODULATION
- ERROR CORRECTION
- AUDIO PERFORMANCE

September 1980

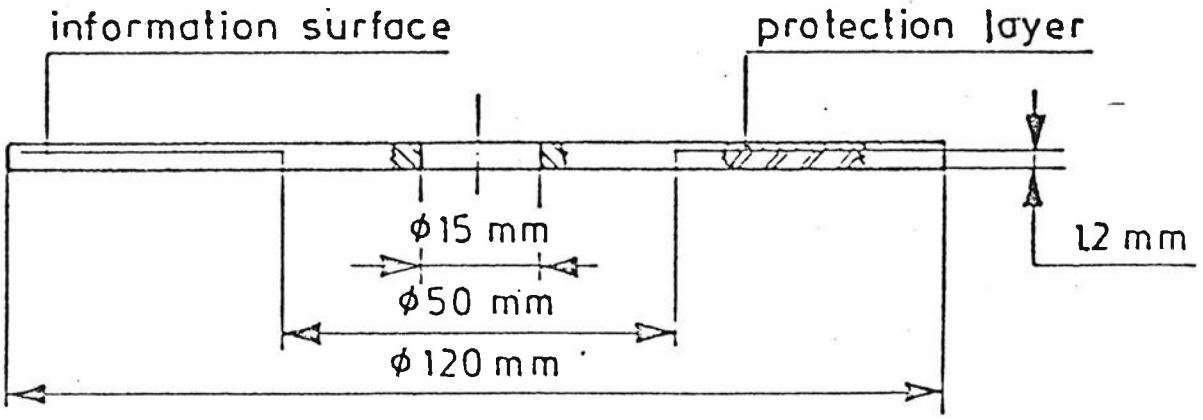
SONY CORP.

N.V. PHILIPS

DISC

- playing time single side, 2 channels	approx. 60 min.
- scanning velocity (2 channels)	1.2 - 1.4 m/s
- sense of rotation seen from reading side	anti clockwise
- track pitch	1.6 µm
- diameter of the disc	120 mm
- thickness of the disc	1.2 mm*
- diameter of centre hole	15 mm
- starting diameter of program area	50 mm

* double sided disc optional



SIGNAL FORMAT

number of channels	2 and/or 4
quantization	16 bits linear/channel
encoding	2's - complement
sampling frequency	44.1 kHz
error correction code	CIRC*
channel modulation code	EFM**
channel bit rate	4.3218 Mb/s

FRAME FORMAT

	Data bits	Channel bits
synchronization		24
control & display	8	14
24 data symbols	192	336
8 error correction symbols	64	112
merging and low frequency suppression		102
Total frame		588

* Cross Interleave Reed Solomon Code

** Eight to Fourteen Modulation

OPTICAL STYLUS

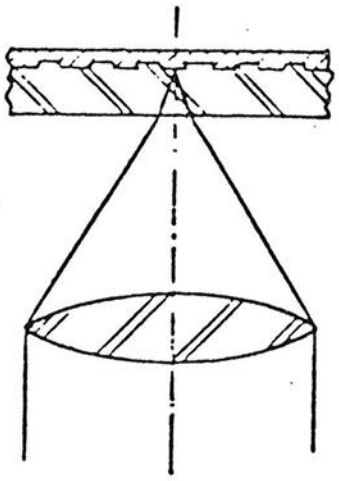
The wavelength λ, and the numerical aperture NA has to fulfil the requirement :

$$\frac{\lambda}{NA} \leqslant 1.75\ \mu m$$

The stylus should be diffraction limited and the information is viewed through a transparent plane parallel plate of 1.2 mm thickness (refractive index ≈ 1.5)

The system is optimized for a wavelength of 0.78 μm (e.g. laser wavelength of AlGaAs).
The depth of focus of the optical stylus is $\pm$ 2 μm.

The method of radial tracking is "differential" and the method of high frequency detection is "integral".



MODULATION SYSTEM

The NRZ* signals from the A/D* converter and the error correction parity generator may have a high dc content and are not self clocking (the run length* is not limited). Therefore they cannot be used on the disc. The signals have to be converted into another code which should meet some special requirements.

1. Requirements

   A. Clock content

   The bit clock must be regenerated from the signal after read out. Therefore, the signal must have a sufficient number of transients and the maximum run length must be as small as possible.

   B. Correct read out at high information densities

   The light spot with which the disc is read out has finite dimensions. These dimensions give rise to intersymbol interference. This effect can be minimized by making the minimum run length as large as possible.
   However, too large a value has a negative influence on the clock content of the signal.

   C. Servo

   The modulation code must be dc free, because the low frequencies of the spectrum give rise to noise in the servo systems.

   D. Error propagation

   The error propagation of the modulation system must be as small as possible.

* Run length = distance between transients in the signal.

NRZ = Non Return to Zero coding

A/D = Analog to Digital

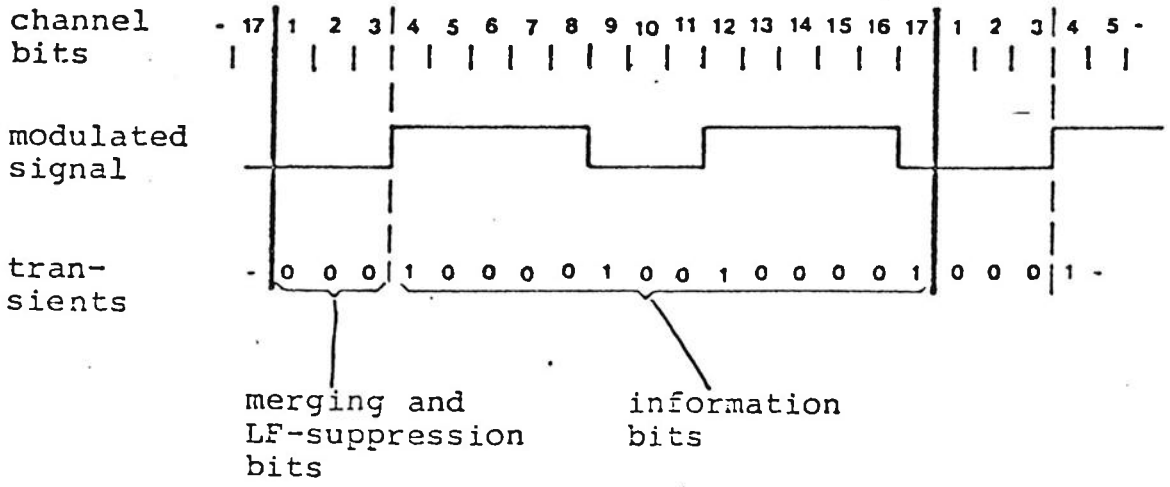
2. Eight to Fourteen modulation code - EFM

- Each block of 8 data bits is mapped onto 14 channel bits. To each block of 14 channel bits 3 extra bits are added, 2 bits for merging the blocks and 1 redundancy bit for LF suppression.

- The information is contained in the positions of the transients. For mapping 8 data bits 256 combinations of channel bits are needed.

- The code is generated in such a way that the minimum distance between 2 transients is 3 channel bits (≈ 1.5 data bits) and the sampling window or eye pattern is 1 channel bit (≈ 0.5 data bit).
  This yields a good compromise between inter-symbol interference and clock accuracy (phase jitter). The maximum run length within the blocks is 11 channel bits (≈ 5.5 data bits).

Example :



- Since the extra 3 bits do not contain any information, an extra transient may be inserted in these bits. In this way the maximum run length (Tmax) in two successive blocks and the dc content of the frequency spectrum can be controlled.

- The modulator and demodulator can be realised with a look up table in a ROM.

- Because of the block structure this modulation code is extremely suitable for use in conjunction with the error correction system, whose operation is based on 8-bit blocks.

3. Frame format

Because the system must be self clocking, synchronization is necessary. Therefore the data stream is split up into frames.

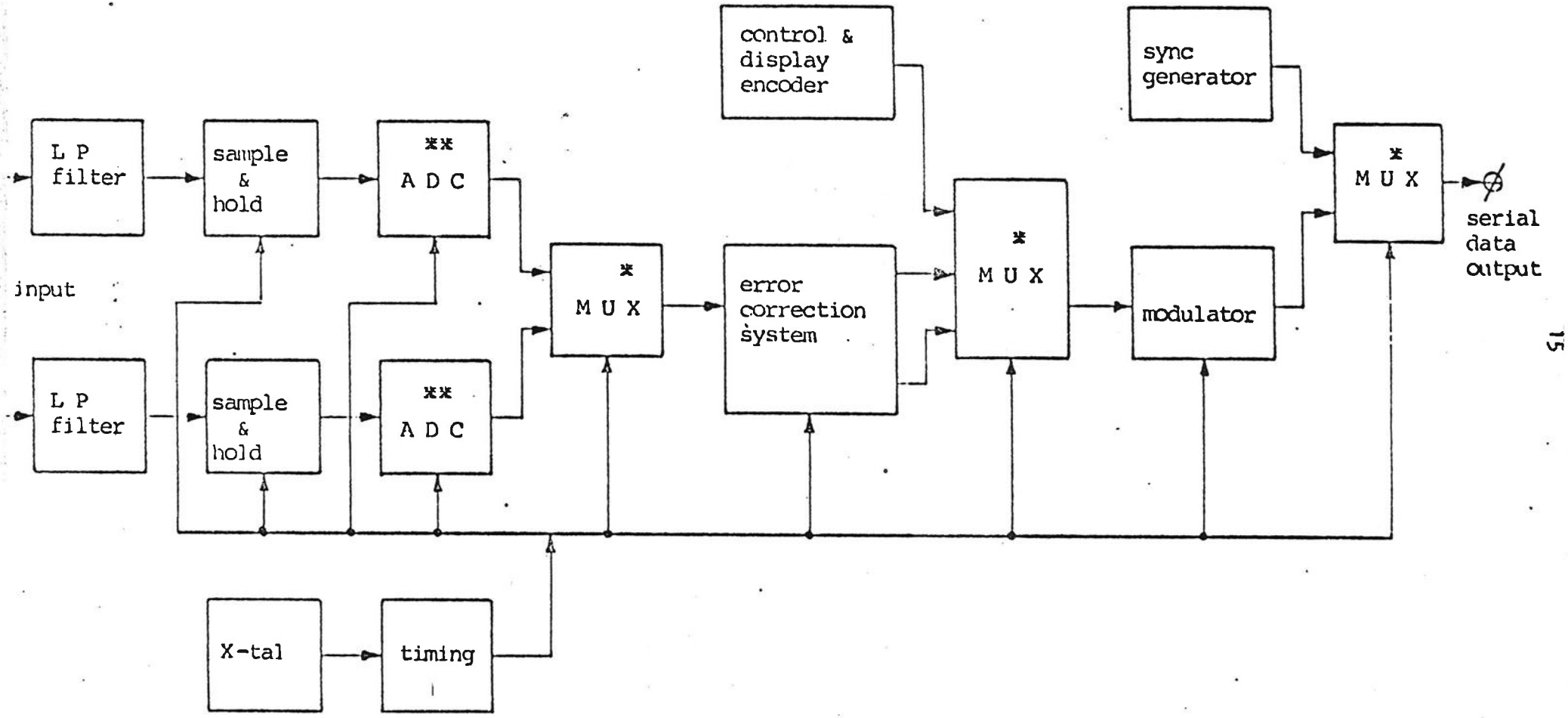
Each frame contents :

- a synchronization pattern of 24 bits
- 12 data words of 16 bits each
- 4 error correction parity words of 16 bits each
- a control & display symbol of 8 bits.

The data and error correction words are each split up into two 8-bit blocks, which are fed into the modulator circuit.
After modulation each block is converted into 3 + 14 channel bits.

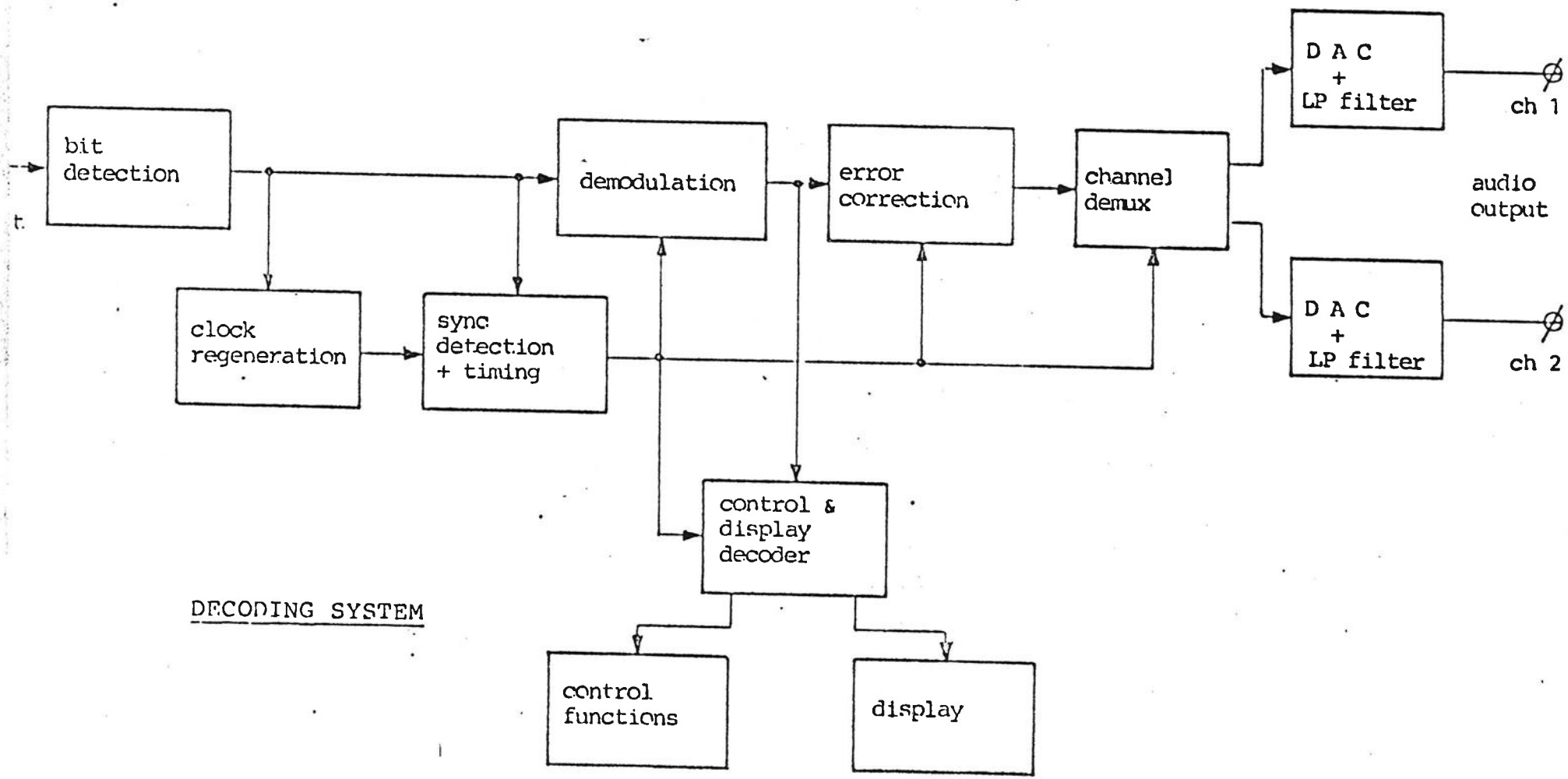
The total number of channel bits per frame is :

- sync pattern	: 24	channel bits
- control & display	: 1 x 14	channel bits
- data	: 12 x 2 x 14	channel bits
- error correction	: 4 x 2 x 14	channel bits
- merging and LF suppression	: 34 x 3	channel bits
Total	588	channel bits



ENCODING SYSTEM

* Time multiplexer
** Analog to Digital Converter



DECODING SYSTEM

ERROR CORRECTION SYSTEM

An efficient error correcting system named CIRC (Cross Interleave Reed Solomon Code) has been developed with different decoder strategy possibilities.
A simple 4-frame correction to a more complex 16-frame correction is possible, keeping full compatibility.

1. Requirements

- High random error correctability.
- Long burst error correctability
- In case burst correction is exceeded, a graceful degradation.
- Simple decoder strategy possibility with reasonably sized external random access memory.
- Redundancy as low as possible (not much parity should have to be added).
- Possibility for future introduction of 4 audio channels, without changes on the decoder chip.

2. Cross Interleave Reed Solomon Code - CIRC

- The code corrects most errors that occur on the disc. However, some error patterns are not correctable. In this situation, the error is detected and the decoder reconstructs the sample value by means of interpolation.

- The performance of the CIRC-code is such that 1000 samples per minute (out of the 2.6 million samples per min.) will have to be interpolated at 10^{-3} BER. If the BER is 10^{-4}, only 1 sample/10 hrs will have to be interpolated. However an avarage BER of 10^{-5} is typical.

- Since the probability that an uncorrectable error is not detected is non-zero, which may lead to a click, the detection capability of the code was designed to ensure less than 1 click per month at 10^{-3} BER.

- A disc handled very roughly, might have scratches: because of that, the code should be capable of dealing with long burst errors. CIRC can fully correct burst errors up to 4000 bits (2.5 mm).

- The decoder complexity of the CIRC code has been reduced considerably by splitting up the decoder into two main parts:

    a. special purpose decoder LSI
    b. standard 2k words of 8 bits

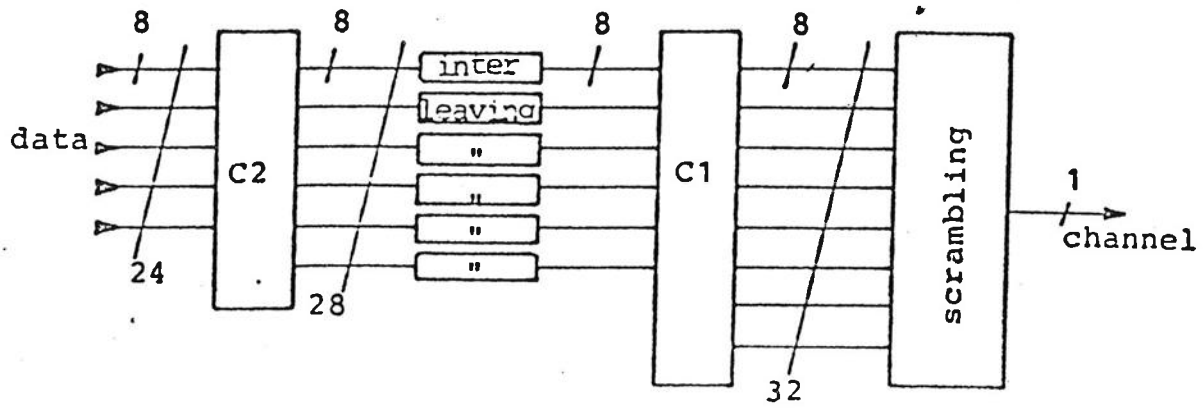
- CIRC has an efficiency of 3/4, this means that 3 data bits will result in 4 bits after encoding.

- The signal format has been designed in such a way that 4 channels are possible in the future, without changes in the decoder chip.

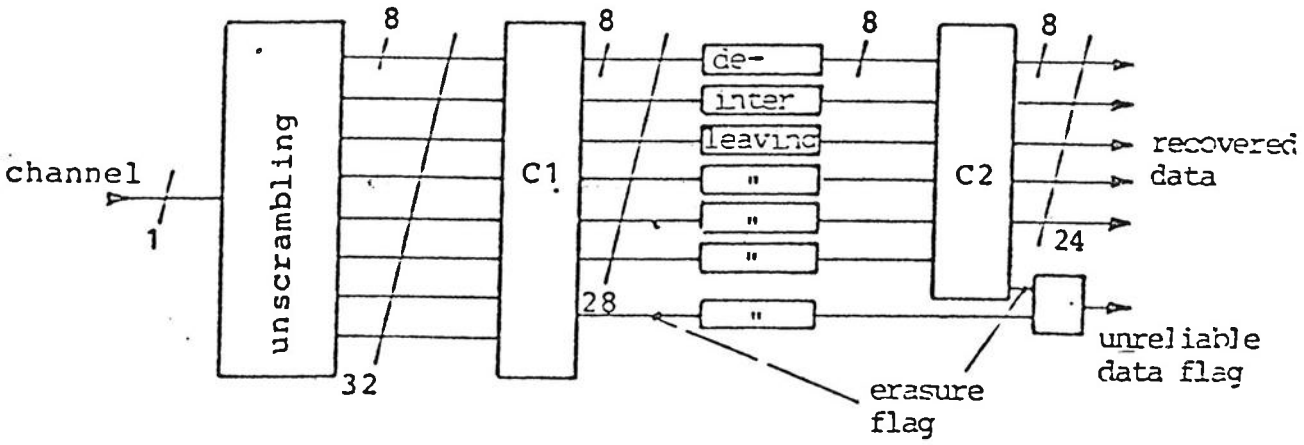
CIRC encoder and decoder

The CIRC consists of a C1 and C2 Reed Solomon Code as described below.

Encoder



Decoder



C1 is a (32, 28) Reed Solomon Code over GF (2^8) *)

C2 is a (28, 24) Reed Solomon Code over GF (2^8)

*) Galois Field

The horizontal blocks between C1 and C2, represent 8 bit wide delay lines of unequal length (interleaving).
Before the C2-encoder a delay of one symbol is inserted in the even words to facilitate consealments in simplified decoder versions.
After the C1-encoder a delay of one symbol (8 bits) is inserted in the even symbols (scrambling).

The decoder operates as follows:

The C1-decoder accepts 32 symbols of 8 bits each ,from which 4 parity symbols are used for C1-decoding.
The parity is generated according to the rules of Reed Solomon coding and because of that the C1-decoder is able to correct a symbol error in every word of 32 symbols. If there is more than one erroneous symbol, then regardless of the number of errors, the C1-decoder detects that it received an uncorrectable word.
If this is the case, it will let all 28 symbols pass through uncorrected, but an erasure flag is set for each symbol to mark that all symbols from C1 are unreliable at that moment.

Because the delay lines between the C1 and C2-decoder are of unequal length, the symbols marked with an erasure flag at one instant, arrive at different moments at the C2-decoder input. Thus the C2-decoder has for every symbol an indication whether it is in error or not: if a symbol does not carry an erasure flag it is error free.
If no more than 4 symbols carry an erasure flag, then the C2-decoder can correct a maximum of 16 frames.
In case even the C2-decoder cannot correct, it will let the 24 data symbols pass through uncorrected, but marked with the erasure flags, originally given out by the C1-decoder.

AUDIO PERFORMANCE

- frequency response	20 - 20000 Hz
- quantization	16 bits linear/channel
- signal to noise ratio	> 90dB
- dynamic range	> 90dB
- channel separation	> 90dB
- harmonic distortion	< 0.05 %
- wow and flutter	equal to X-tal osc. accuracy